Questions and challenges of an underground multi-kton LAr TPC detector

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Outline

- Introductory Remarks
- Detector Optimization
- Vessel construction and integration
- Cryogenics and Purification
- Readout

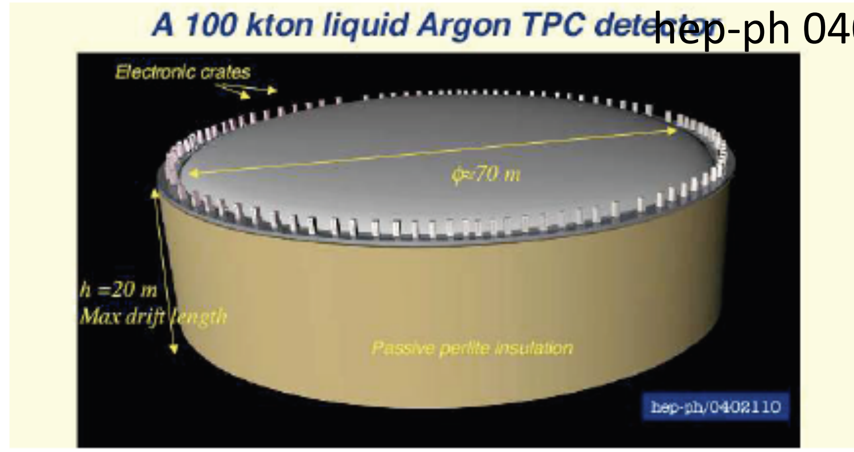
Introductory Remarks

- There is a growing interest in LAr TPCs due to its unique capabilities:
  - 3D-imaging: full event topology reconstruction
  - Precision calorimetric measurements
  - PID through dE/dx (low momentum particles)
  - Higher sensitivity to ν physics and for some of the proton decay channels (e.g. $p \longrightarrow K\nu$)
- However the feasibility of multi kiloton detector is yet to be proven.
  - R&D plans are growing fast. Getting organized. Needs support.
- Technical challenges and questions here:
  - 0^{th} order: applicable to multi-kton scale (5k,20k,100k)
- Not addressing questions related to the near detector (smaller scale): microBooNE detector?

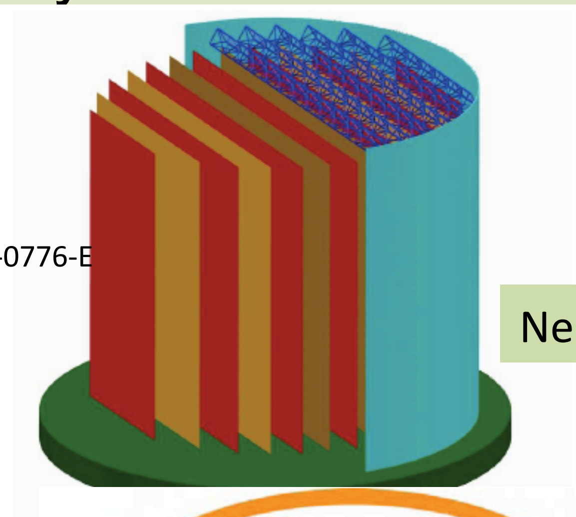
Detector Designs

- Different designs and proposals over the last few years:

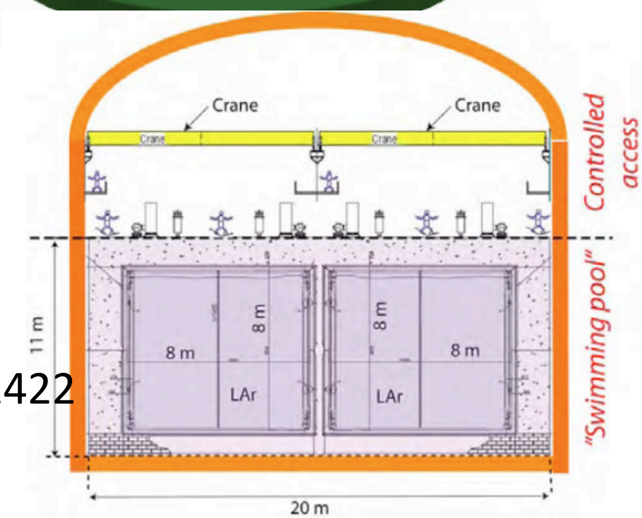
GLACIER
hep-ph 0402110



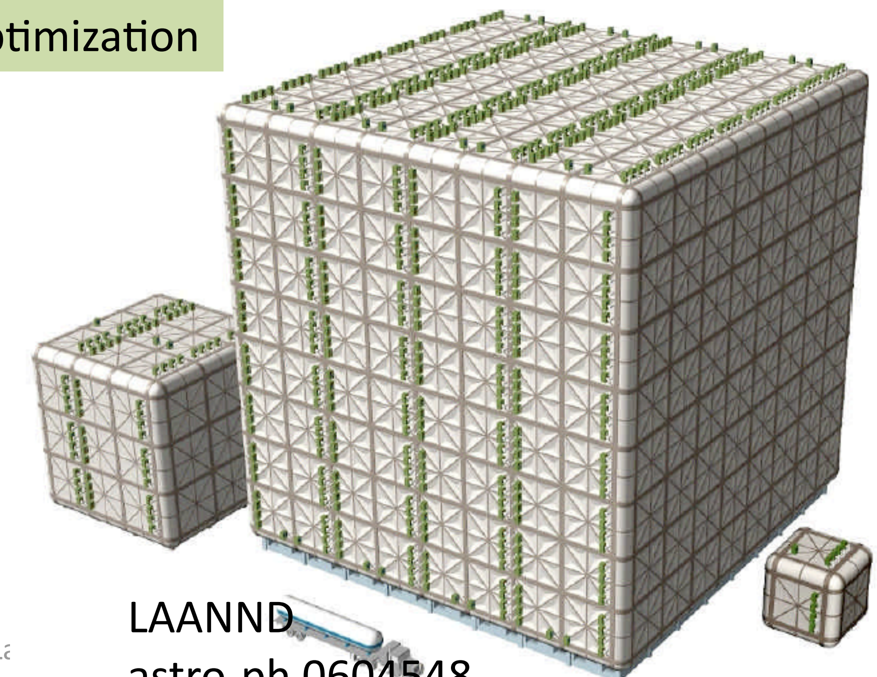
LArTPC
FERMILAB-FN-0776-E



Needs optimization



MODULAr
hep-ph 07041422

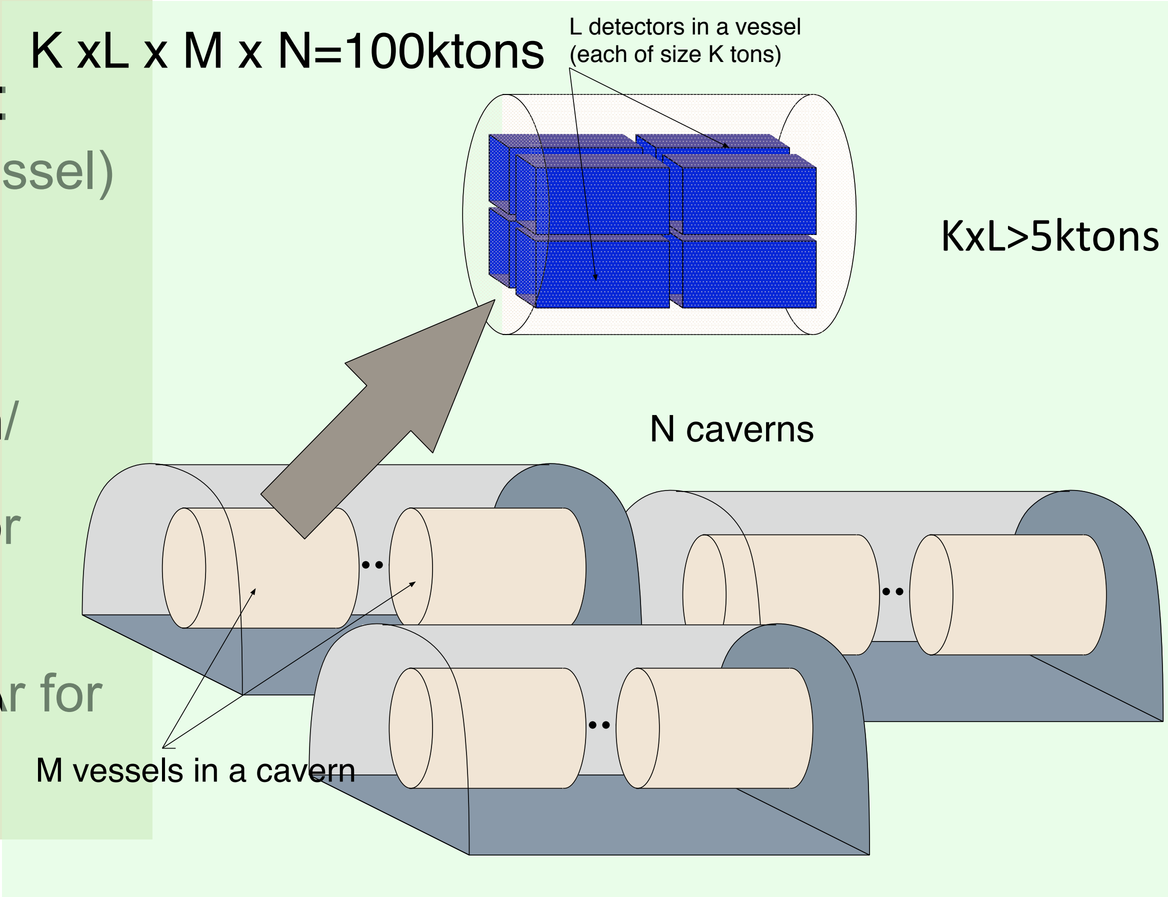


LAANND
astro-ph 0604548

Detector Design and Optimization

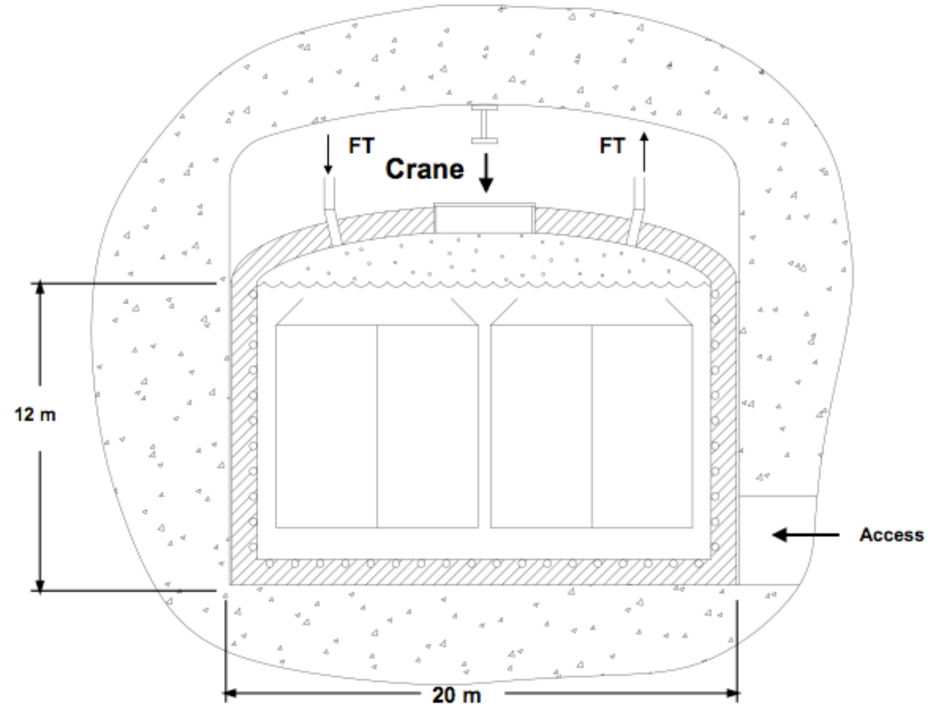
(rewording B. Fleming presentation @ SLAC P5 meeting – Feb 2008)

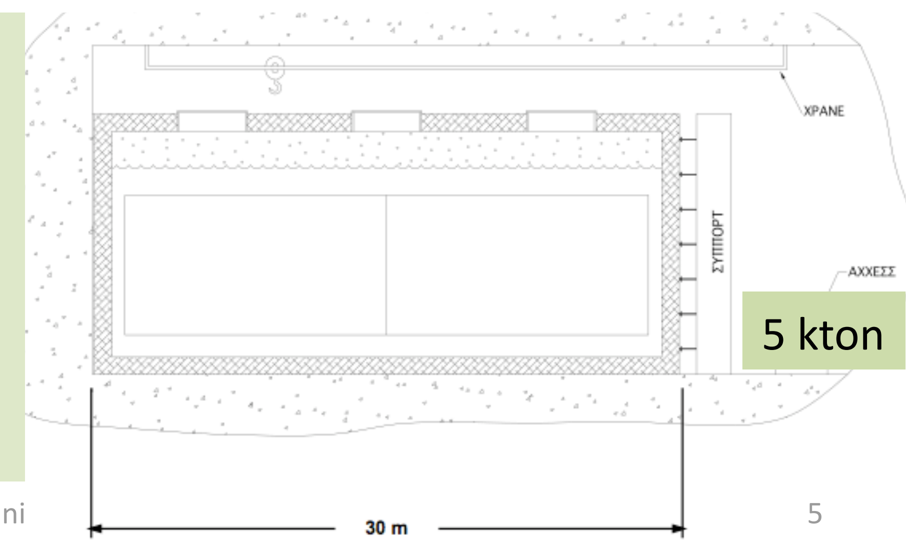
- Depth?
- Modularized Option.
- Optimization against :
  - Costs (Cavern and Vessel)
  - Technical Feasibility
  - Schedule and Staging options
  - Risks (e.g. purification/ contamination compromising detector operations and performance)
  - Safety (recovery of LAr for severe failures)



Cryostat Vessel

- Construction:
  - Non-”evacuable”
  - Single Vessel containment + Insulation?
    - Industrial vessels? LNG tanks?
  - Rock stability: can the walls be used a structural element?
  - Materials: glass foam insulation, inner wall liner
  - Heat Loads
    - Refrigeration and cooling loop
- Access, Assembly and Integration:
  - Single access: through top door?
  - Contamination: clean room requirement?
  - Heavy Material handling
  - Assembly sequence



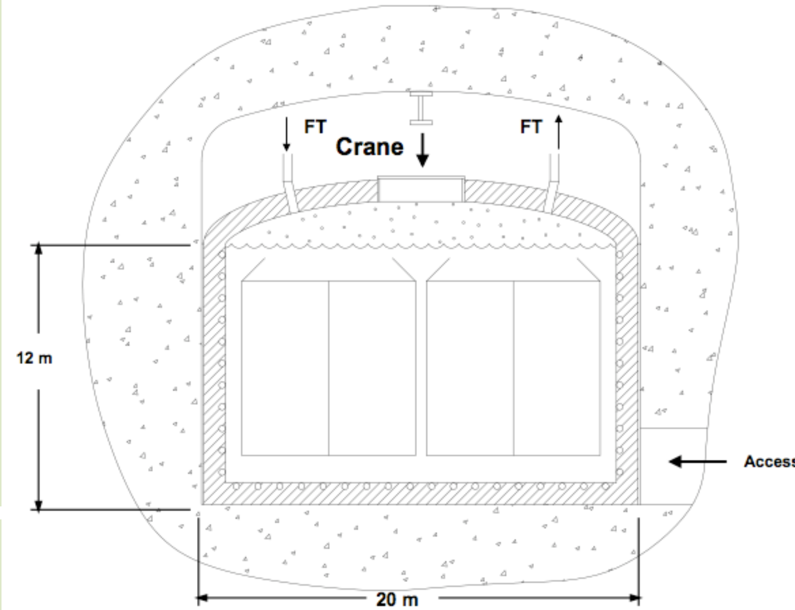


Cryogenics and Safety

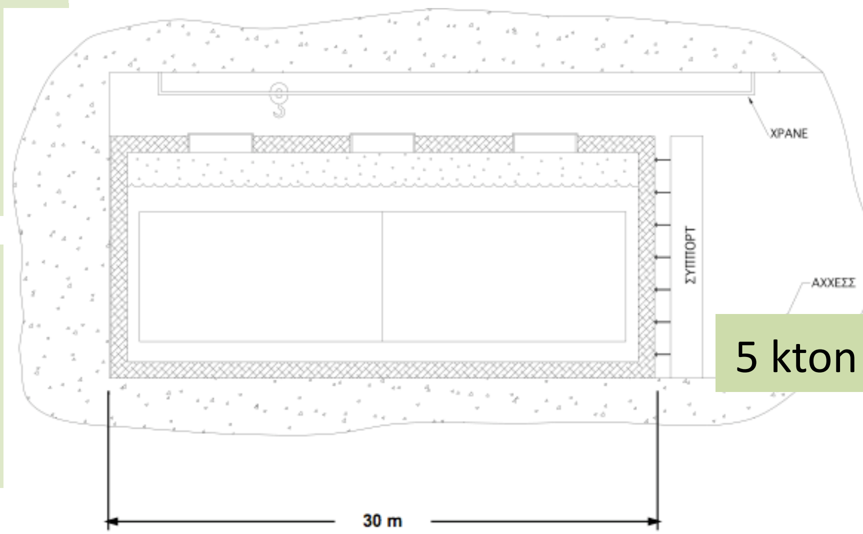
- Vessel needs a relief valve and a way to evacuate LAr in case of an accident
- Do we want to try to recover LAr in case of an accident?
  - Large storage facility above ground and pumps to evacuate the Argon
  - Extra vessel underground?
- Catastrophic failures:
  - Abandoned tunnel as “dump” and then slowly get the L/G Ar out from that tunnel?
- Safety aspects during assembly of the experiment
- …in regular running

Cryogenics: Heat Load

- Example of a ~5kton detector
- Heat Load: 15kW
  - through the walls and the floor: 9kW
  - Roof+FT (guesstimate): 6kW
  - Boiloff 0.15% of the total volume per day
- Scaling to a ~20kton detector: 35-40kW



- Assuming a ~20kton vessel with cold electronics
  - 40mW/channel
  - ~250k-1M channels
  - Heat Load: 10-40kW

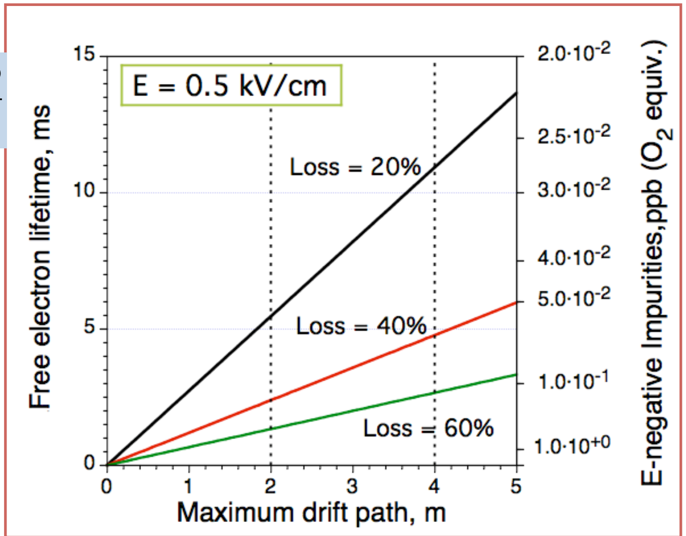


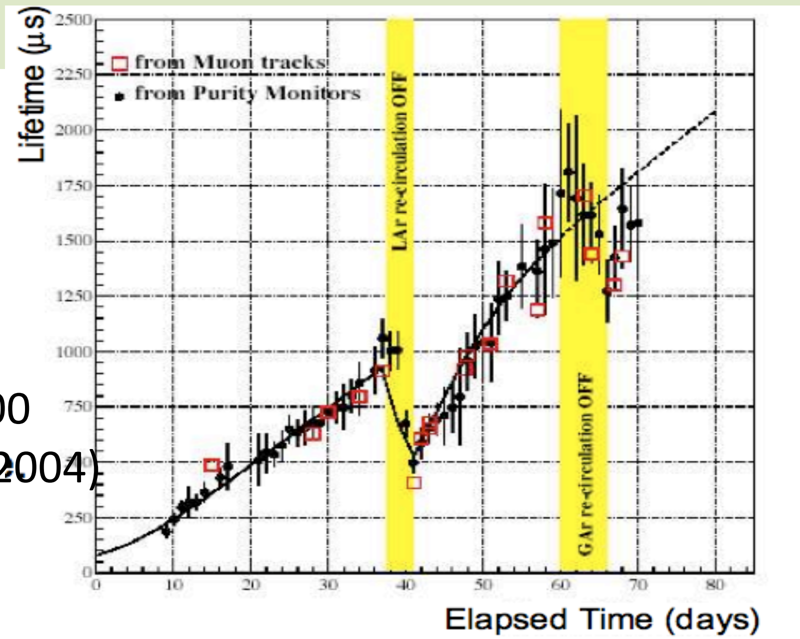
- Total Load: ~50-80kW(for a 20kton), [250-400kW (for a 100kton detector)]
- Refrigerator and LN2 storage nearby? Surface?

Cryogenics and Purification

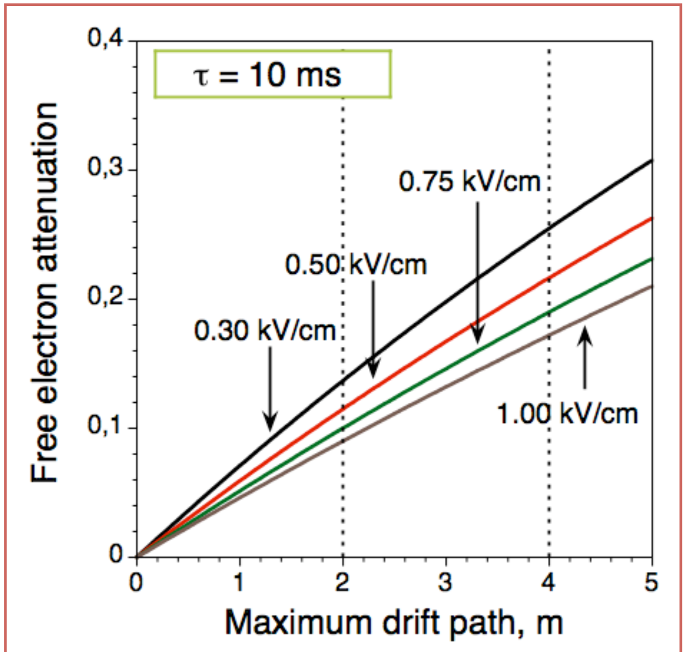
- Electron drift several (2-5) meters, i.e. T_D~3-8ms
  - Maximum Drift Path
  - Drifting Electric Field
  - Purity Levels (O2 equivalent) allowed
  - Other (than O2) electronegative impurities?
- Purification Systems:
  - Gas vs. Liquid Phase (both ala Icarus?)
  - Re-circulation rate needed
    - Oxysorb (single pack ~120m3/day) and molecular sieves? Other devices?
    - Purification system near/(inside?) each vessel?
- Initial filling assuming no evacuation:
  - Purging (gas-cycles, impurity freeze-out through LN2??)
- LAr contamination: material testing for detector and readout construction

$$\tau \simeq 300\mu s \times \frac{1.0\text{ppb}}{\text{N(O}_2)}$$





ICARUS T-600
NIM A516 (2004) pp. 68-79

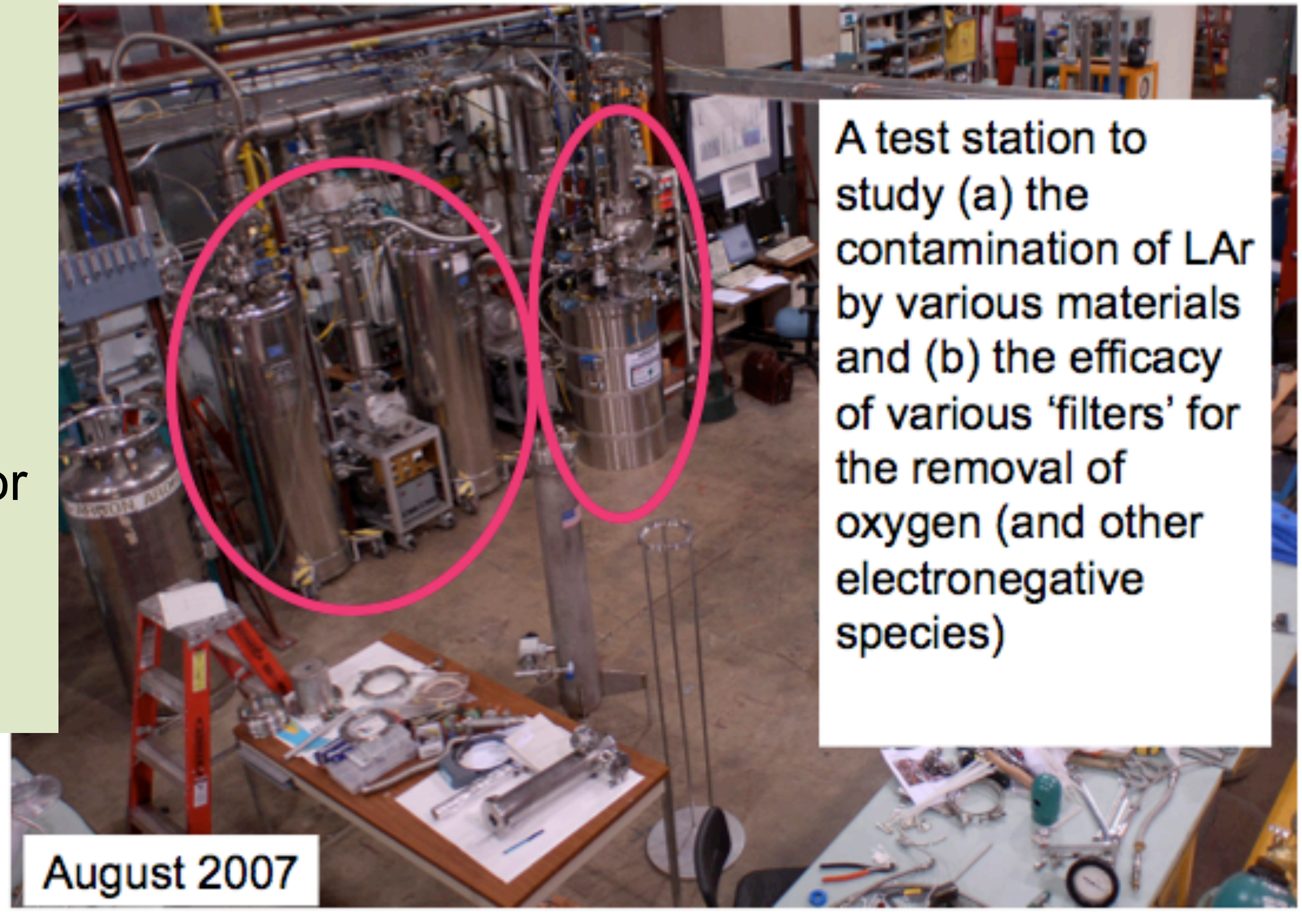


C. Montanari, Criodet-2, LNGS (Jun 2007)

Cryogenics and Purification

- Lots of R&D required
- Small scale Test Stands already existing at FNAL
  - … being used or planned to be used also for microBooNE material testing for example
- Purging tests also planned at Fermilab on purity demonstrator vessel (20 tons)
  - … and proposed by the microBooNE collaboration

Materials Test Station



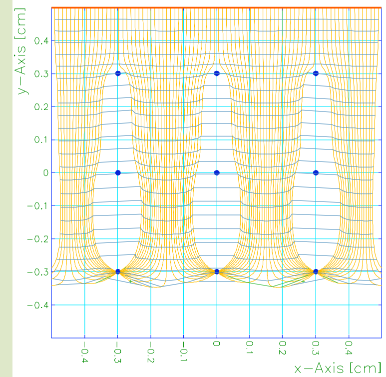
Have tested two items and are developing systematic discipline (figuring out what it is telling us).

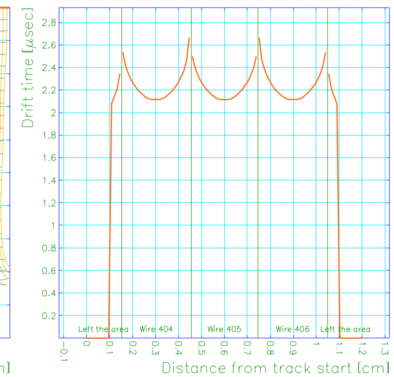
David Finley / Fermilab at NNN07 Hamamatsu Japan October 4, 2007

Slic

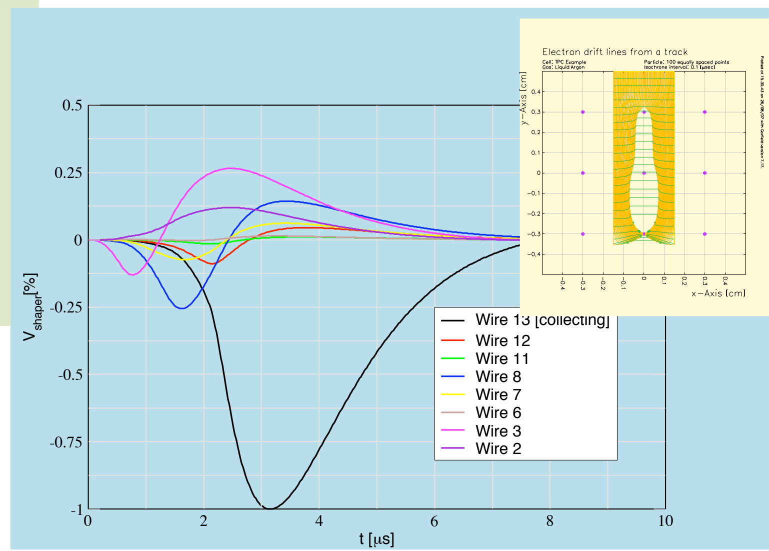
Readout and Detector Geometry

- Detector Layout Optimization:
- Assuming double-module geometry (HV middle plane, 2 readout plane set on the side)
  - Similar scheme as ModuLAr, geometry ala microBooNE
- Dimensions:
  - Maximize drift distance (limited by purity, HV ....)
  - Wire planes (1 collection, 2 induction planes, additional grid?)
  - Wire orientation
  - Wire length, pitch [3-6mm]
  - Materials (minimize resistance: SS+Au/Ag/Cu plating, CuBe)
    - Readout S/N
  - Wire Termination schemes
- Double-Module Dimension:
  - 2x4x8x15x1.4 = 1.3 ktons
  - 5kton : 4 double modules
  - 20 kton: 16 double modules





- Nr. Of channels:
  - ~2*2*15000/3(5) ~ 12-20k/module
  - 5kton: 50-80k
  - 20kton: 200k-320k
  - 100kton: 1M-1.6M



(from microBooNE proposal – Oct 2007)

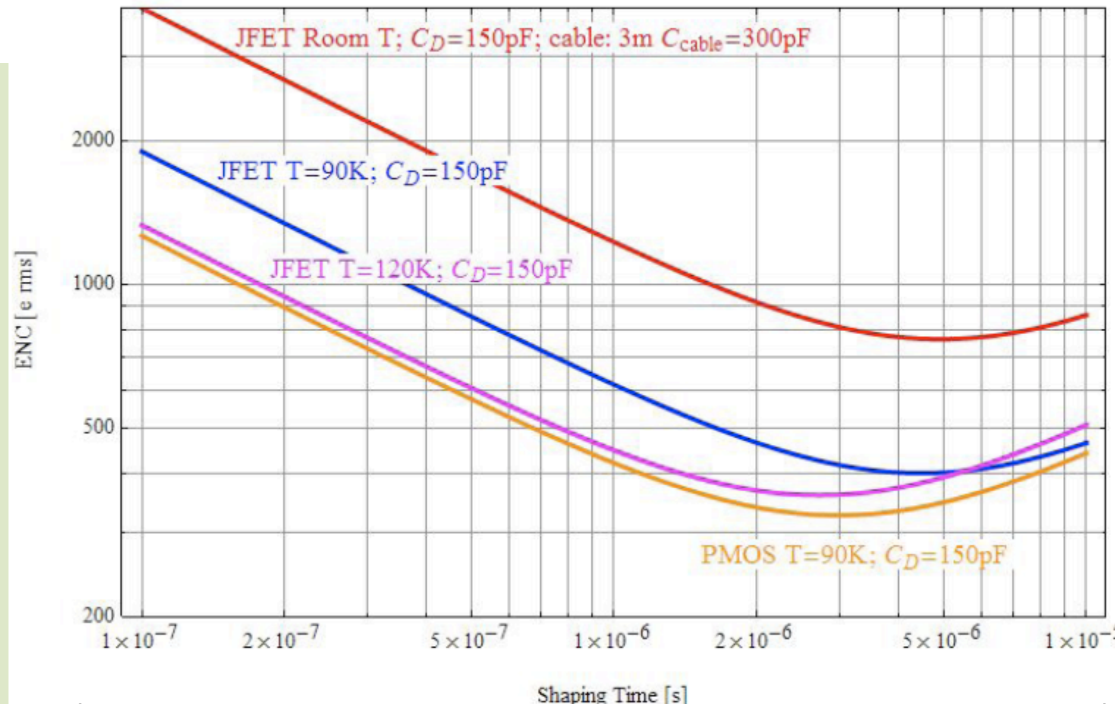
Readout Optimization

- Requirements and Optimization
  - “Track” resolution: shaper peaking time [1-2us]
  - S/N: minimization of noise: again peaking time and cold electronics
  - Sampling Frequency and Dynamic Range
  - Signal Processing/Optimal Filtering/RT Reconstruction (partly integrated in DAQ)
  - Architecture based on continuous wfm recording:
    - 0-suppression
    - Peak-finder/time-slice/Self-Triggering
  - Reduction of vessel penetrations: MUX’d architecture

- Trigger/T0 determination
  - PMTs, fiber-based optical readout

Readout: Cold Electronics

- Best S/N obtained by:
  - Minimizing the length of connections between detector elements and preamplifier inputs
  - Cold electronics to (pMOS processes) optimized performance at cryogenic temperature
  - Factor ~3 at least better than at room T

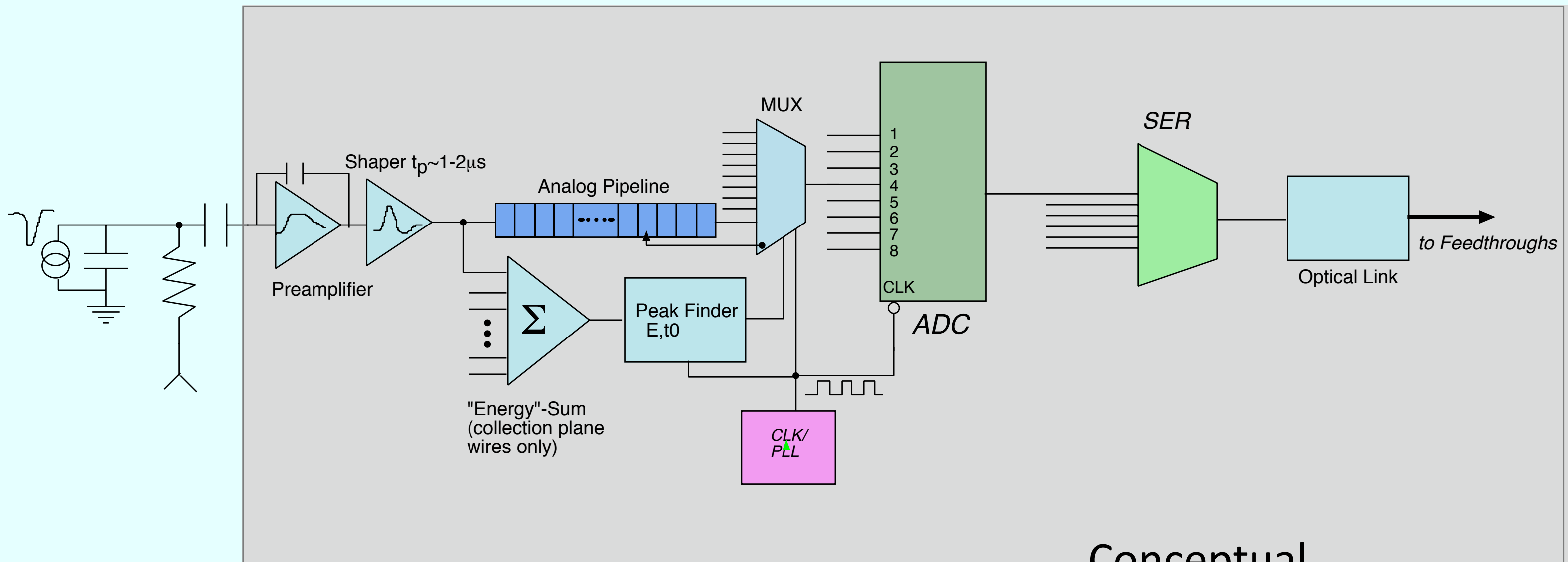


(from MicroBooNE proposal's addendum – Mar 2008)

- Extensive R&D Program required:
  - Assess p-MOS technology at cryogenics temperature (packaging, reliability etc.)

Readout: MUX

- 100kton LAr ~ 250k-1M channels
- Issues:
  - Cable factory
  - Feedthroughs
  - Heat Load
  - S/N
- R&D on a multiplexed readout architecture and integration scale (analog+digital?) of possible ASIC
  - Minimize power
  - 4 years (at least)
- Steps:
  - Analog Front-End (PA+Shaper, Peak Finder)
  - Analog Pipeline/ MUX
  - Digitization and transmission



Conceptual

Summary: R,D and R&D Programs

- Cavern: depth, shape,size, optimization
- Vessel Design: Materials, insulation, feedthroughs, cavern interface, access and assembly, integration issues
- Cryogenics: Refrigerator Size and location, LAr fill , dump and evacuation/recovery/storage.
- Purification: large system purification, purging during initial filling
- TPC design: wire plane structure, materials, geometry/layout optimization
- Readout: Low Noise Cryogenics Electronics, MUX and Data Reduction
- Readout/Trigger: T0 determination (light detection?)
- Physics R&D: Signal Processing, Optimal Filtering techniques, Event reconstruction
- Safety Issues – at each step we need to understand the safety issues and requirements of working underground.

Summary/Conclusions

- LAr TPC are powerful detectors for a wide “range” of physics
- Ultimate physics capabilities need more detailed studies
- Technical challenges need to be understood to assess feasibility of large scale detectors:
  – First understand issues related to underground operations of cryogenic detectors
    - … some are common to the ones of large WC
- Second to make rapid progresses the R&D program needs:
  – Organized working groups/large collab.
  – Significant Resources
  – Financial Support!